



# Improved Backup Alarm Technology for Mobile Mining Equipment

By Guy A. Johnson, Russell E. Griffin,  
and Linneas W. Laage



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<p>Despite the use of warning alarms to alert miners to the backward movement of large mining equipment, miners still are injured too frequently in backup accidents. Currently approved backup alarm technology consists of continuous sounding alarm systems. New technology has developed a warning system that initiates an alarm only if there is an object close behind the vehicle. This advancement eliminates constant exposure to the alarm because a warning is given only in case of a potential collision. Adoption of this development can improve safety and reduce damage, especially for front-end loaders. It will also eliminate a source of nuisance noise in urban and residential areas. This Bureau of Mines report describes the general characteristics of infrared light, ultrasonic wave, and Doppler radar technology as used for backup alarms, and reviews the testing of the most promising detection devices.</p>			
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# UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	rpm	revolution per minute
ft <sup>2</sup>	square foot	st	short ton
g	gram	V	volt
GHz	gigacycle per second	V ac	volt, alternating current
h	hour	V dc	volt, direct current
m	meter	yd	yard
ms	millisecond	yd <sup>3</sup>	cubic yard
mW	milliwatt	yr	year
pct	percent		



## IMPROVED BACKUP ALARM TECHNOLOGY FOR MOBILE MINING EQUIPMENT

By Guy A. Johnson,<sup>1</sup> Russell E. Griffin,<sup>2</sup> and Linneas W. Laage<sup>3</sup>

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### ABSTRACT

Despite the use of warning alarms to alert miners to the backward movement of large mining equipment, miners still are injured too frequently in backup accidents. Currently approved backup alarm technology consists of continuous sounding alarm systems. New technology has developed a warning system that initiates an alarm only if there is an object close behind the vehicle. This advancement eliminates constant exposure to the alarm because a warning is given *only* in case of a potential collision. Adoption of this development can improve safety and reduce damage, especially for front-end loaders (FEL's). It will also eliminate a source of nuisance noise in urban and residential areas.

This Bureau of Mines report describes the general characteristics of infrared (IR) light, ultrasonic wave, and Doppler radar technology as used for backup alarms, and reviews the testing of the most promising detection devices.

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## NOTICE

## IMPROVED BACKUP ALARM TECHNOLOGY CAN BE APPLIED IN TWO WAYS

1. As a supplement to conventional backup alarms by sounding an additional alarm in the cab when a collision hazard is detected.
2. As a switch for the conventional backup alarm, sounding the alarm only when a collision hazard is present. With conventional backup alarms the operator is expected to work the machine despite the alarm. With the improved backup alarm both the potential victim and the operator can respond to avert a collision because the false alarm aspect is eliminated.

## CAUTION

The following statement was prepared by the Director, Office of Standards, Regulations, and Variances, Mine Safety and Health Administration, for installations where the conventional backup alarm is switched on by the improved backup alarm (method 2 above).

"Since the discriminating backup alarm does not give an automatic warning when the mine machine is put in reverse, it cannot be used to satisfy existing Federal requirements unless a petition for modification has been issued by the Mine Safety and Health Administration; therefore, anyone who would like to use the device will have to file a petition. This petition must be in writing to the Assistant Secretary of Labor for Mine Safety and Health."

"The petition must contain the name and address of the petitioner; mailing address and identification number of the mine or mines affected; the mandatory safety standard to which the petition is directed and a concise statement of facts that would warrant the proposed modification."

## CAUTION

These systems must be installed and aimed properly to detect collision hazards.

These systems must be regularly inspected for operation and performance.

## INTRODUCTION

The Mine Safety and Health Administration (MSHA) (30 CFR 56.9087, 57.9087, and 77.410) requires "an automatic reverse signal alarm" on mobile surface mining equipment. These alarms usually are loud horns or bells on the rear of the equipment which are activated and in continuous operation when the vehicle's transmission is shifted into reverse. Their purpose is to warn miners of the rearward movement of the vehicle.

As part of its research to develop collision protection technology for larger mobile mining equipment, the Bureau of Mines analyzed the occurrence of backup accidents. Bureau investigators reviewed fatality reports and held informal discussions with such safety organizations as the Lake Superior Mines Safety Council, the Association of Arizona Mine Safety Engineers, the Wyoming Chapter of the American Society of Safety Engineers, and the Safety Section of the National Sand and Gravel Association. Results of this study show that back-over accidents still occur regularly, apparently because miners can become "immune" to the sound of current backup alarms.

Semicontinuous backup alarms inevitably produce the effect of a "false alarm," and repeated false alarms desensitize people exposed to them. The U.S. Army recognized this in Military Standard 1472: "The design of audio display devices and circuits shall preclude false alarms."<sup>4</sup>

In mines, workers are constantly exposed to the repeated sounds of many backup alarms on various pieces of equipment. Consequently, they tend to pay little attention to any one specific warning. This is especially true for maintenance and ground crew personnel who constantly work near FEL's.

To counteract this problem, the Bureau of Mines has adapted and developed sensors that will automatically turn on a backup alarm *only* when some object

(collision hazard) is behind a vehicle at a distance of 15 to 20 ft. If a warning is given only when the danger is real, it will get a greater response both from miners on the ground and from equipment operators.

The Bureau reviewed the literature to determine the maximum proximity range at which sensors could be made rugged enough to be reliable in mines at a reasonable cost. Several options were found. Recent advancements in microcircuitry technology make it easy to fabricate the electronic components for area and driver warnings once the proper detection sensors have been selected.

Military-type detectors were studied first and found to be reliable but very expensive. Viability and low cost were both essential, and the fast-growing field of security and intrusion detectors offered promise. The security field has created a large market for sensors that give close-in object detection; for example, a sensor with the ability to detect the presence of a person sneaking across a room. Because of the economics of scale inherent in this market, relatively sophisticated sensing technology is now available at a very reasonable price.

In the early 1980's, the Bureau began testing, first in the laboratory and then in the field, prototype devices with a potential for solving the backup collision problem. Although improvements in mirrors, the development of blind area viewers, and advancements in closed circuit television already had made it easier for the operators of large equipment to see potential hazards, alarms still were needed to direct the attention of drivers, and potential victims, to specific dangers.

In addition to solving the "false alarm" problem, an alarm that sounds only when a hazard exists can help to minimize the nuisance noise that extends to a mine's surrounding environment. Such noise is especially irritating in the early morning and evening hours around urban crushed stone or sand and gravel pits. Even though the miners often do not react to the backup alarms,

<sup>4</sup>U.S. Army. Human Engineering Design Criteria for Military Systems, Equipment and Facilities. Military Standard 1472C, 1984, p. 51.

people living close to the operations are constantly bothered by the noise. Alarms that sound only when something or someone

is behind and close to a vehicle will be a boon to both mines and their neighbors.

#### GENERAL PRINCIPLES--DESIGN CRITERIA

In addition to the considerations presented above, a few key principles have emerged from the Bureau's research into improved protection for backing vehicles. The "target area" behind the vehicle is relatively close, around 15 to 20 ft. (See figure 1.) Objects beyond this area are not a major hazard because they can be seen either in the vehicle's mirror or directly by the driver when the backing vehicle is turning. The rear-looking detector(s) are not just for sensing individuals or other vehicles. These systems can detect objects as small as 1 ft<sup>3</sup> (e.g., boulders, stacks of maintenance materials, etc.) and warn of their presence.

This warning is accomplished when the hazard detection system initiates an in-cab backup horn or buzzer to alert the driver. (See figure 2.) An in-cab buzzer can be added to the system when vehicle cabs are acoustically isolated from

the external backup alarm. This in-cab warning feature uses modern, miniaturized electronic components that are low in cost. It is also cost effective because it alerts the driver to the possible presence of small objects that could damage the vehicle's tires, thus avoiding both the high material cost and lost time involved in replacement.

During the Bureau's research, several alternative technologies were examined. In 1982 and 1983, after a few simple infrared (IR) obstacle detection devices had been tested, a rugged unit produced by Scientific Technology, Inc. (STI),<sup>5</sup> Mountain View, CA, was found to give adequate coverage and distance during laboratory testing. (The IR sensor option is discussed in the next section.)

<sup>5</sup>Reference to specific products does not imply endorsement by the Bureau of Mines.

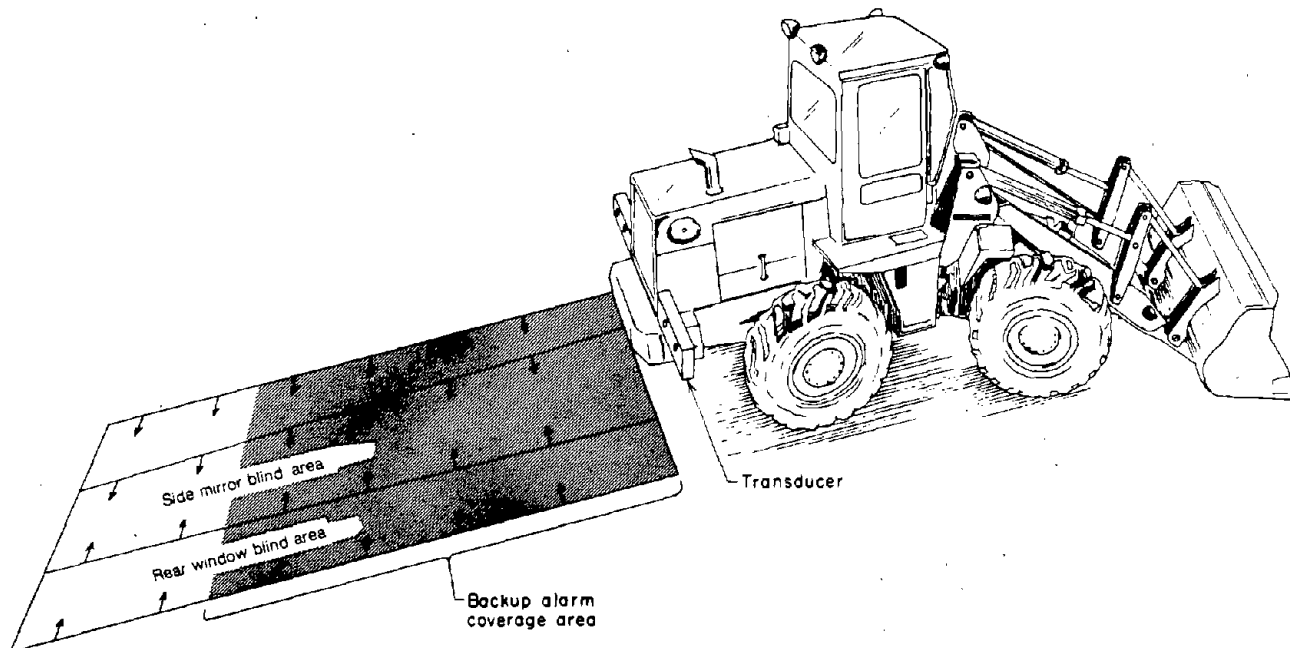


FIGURE 1. - Discriminating backup alarm design.

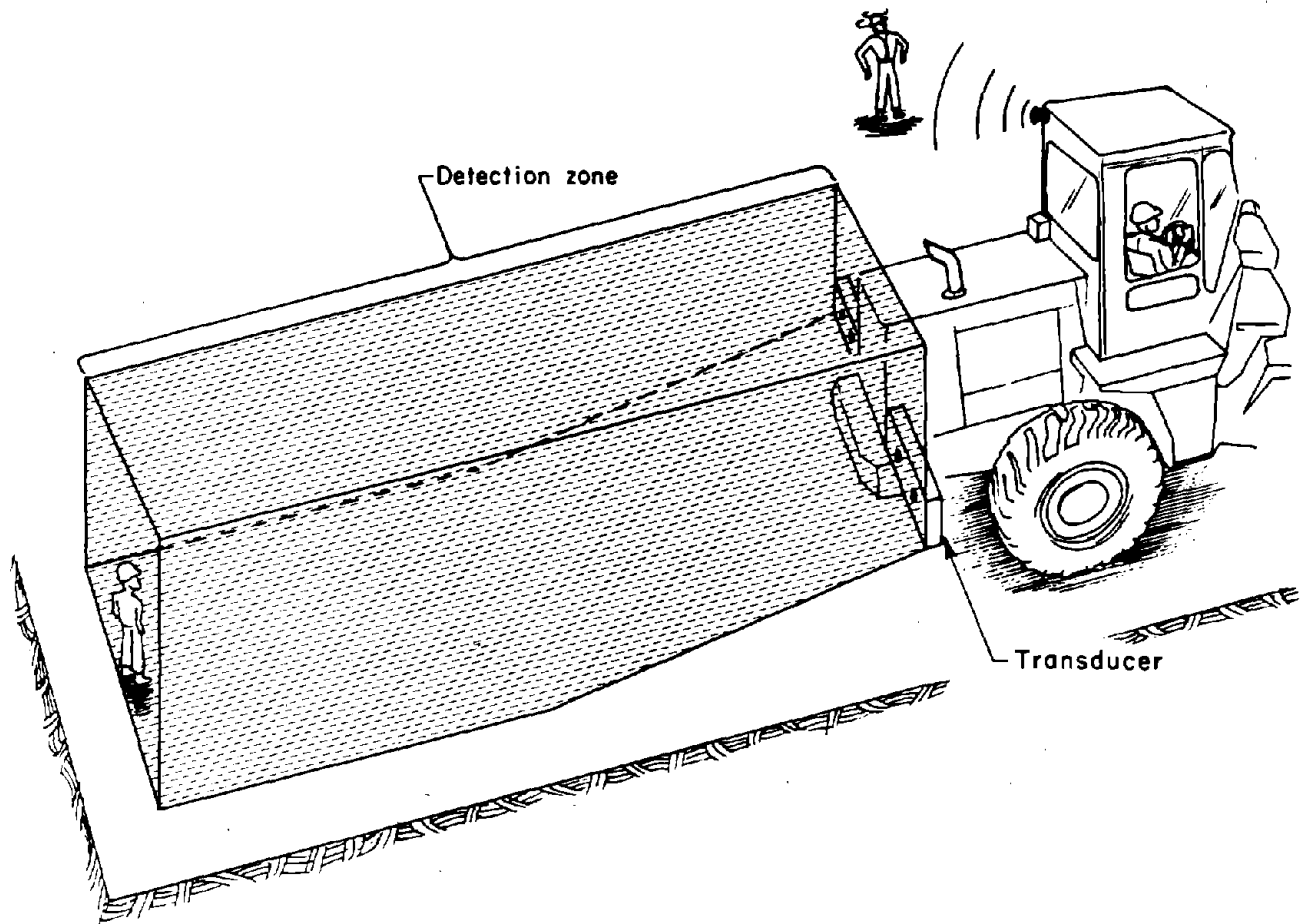


FIGURE 2. - Ideal detection zone.

Polaroid has packaged its ultrasonic ranging transducer (used on its cameras) for general use. This device was tested on a 24-yd<sup>3</sup>-capacity FEL and a 120-st-capacity haulage truck at the Bureau's Twin Cities (MN) facility, but the beam pattern was found to be too limited in diameter for on-vehicle use. (Followup work with a more sophisticated, long-range, ultrasonic system prototype for use on small construction equipment is also reported below.)

The most recent work involves a newly developed short-range Doppler radar unit. In the late 1970's, radar collision protection was tested but found only practical for long-range (100- to 300-ft) applications because of signal processing circuitry limitations. The new Doppler radar systems are designed for close (4-ft) collision protection, so increasing the range is now a problem. Once the hardware modification problems can be worked out of this unit, it will be the most promising alternative yet tested.

#### PROOF-OF-CONCEPT TESTING OF PROTOTYPE SYSTEMS

The work detailed here is an extension of the Bureau's earlier efforts to use state-of-the-art technology in solving visibility problems inherent in large

surface equipment. Table 1 summarizes the testing of discriminating backup alarms. Table 2 summarizes the characteristics of the backup alarm systems.

TABLE 1. - In-mine tests of discriminating backup alarm systems

System type and location	Testing dates	Equipment tested on	System range, <sup>1</sup> ft	Comments
<b>Infrared:</b>				
Limestone quarry (MD).	Mar.-Sept. 1983.	Terex 90C..	Up to 40...	System had to be removed and made more rugged.
Sand mine (MN)..	Oct.-Dec. 1983.	Clark 275..	Up to 40...	System removed owing to light sand-sun reflection problems.
Sand and gravel pit (CO).	July 1984-present.	Caterpillar 980.	Up to 40...	Marginal usage because of moisture condensing inside lens.
<b>Ultrasonic:</b>				
Limestone quarry (MD).	Mar. 1984-June 1985.	Caterpillar 988B.	Up to 17...	Working well.
Sand mine (MN)..	May 1984-present.	Clark 275C.	Up to 17...	Working well.
<b>Doppler radar:</b>				
Sand and gravel pit (MO).	Mar. 1985-present.	Caterpillar 992.	Up to 18...	Initial interference between back-up alarm and cab annunciator. Corrected by a modified unit.
Sand and gravel pit (CO).	Feb. 1985 (1 day).	Caterpillar 988.	Up to 18...	Switch problem at installation.
Sand mine (MN)..	May 1985-present.	Clark 275C.	Up to 20...	Maintenance problem, which was resolved.

<sup>1</sup>Depending on size and reflectivity.

TABLE 2. - Characteristics of backup alarm systems tested

System type and manufacturer	Shape of area coverage pattern	Performance affected by--
Infrared: Scientific Technology, Inc.	2 parallel narrow cones extending from sensors.	Sunlight, dust, reflectivity of object.
Ultrasonic: Global Fabrications Co., Ltd.	11- by 17-ft rectangle..	Airflow, acoustical reflectivity of object.
Doppler radar: Con-Serv, Inc.	12- by 20-ft elongated teardrop.	Radar profile of object.

#### INFRARED SYSTEMS TESTED

##### STI Omniprox 3070

The STI Omniprox 3070 series sensor was the first of the IR type to be laboratory and field tested. This sensor is a solid-state, modulated, IR beam detection and control device, provided in a modular configuration. The sensor head is totally sealed and shock tested (100 g at 10 ms). The manufacturer states it can be

mounted anywhere--indoors or outdoors, submerged or in a vacuum--and can be located up to 30.5 m (100 ft) from the control electronics. (Figure 3 shows the unit mounted on a FEL.) It is capable of disregarding ambient light (though direct sunlight does affect it), atmospheric contamination, and thin film accumulations of oil, dust, water, and other airborne deposits. Field tests support these latter claims.



FIGURE 3. - Infrared sensor mounted on front-end loader.

The system is limited in its area of coverage. The 3070 series has an adjustable range of up to 3.7 m (12 ft) in the proximity mode (target size 12 in) and 18 m (60 ft) in the retroreflective mode. The range sensitivity is adjustable through a potentiometer on the control electronics. The maximum IR beam is typically 2-ft diam at a distance of 20 ft, which is too narrow for general in-mine use.

A variety of standard output and control options are available to adapt the system for different applications. For the Bureau tests, however, it was used with two sensors with overlapping beams, in a logic "or" mode with a double-pole, switched-relay output. With this setup, either sensor detecting an object can activate a backup alarm, an audio in-cab alarm, or a light, in any combination desired. It is also designed to easily adapt to operation on 115 or 230 V ac, 10.5 to 13 V dc, or 24 V ac or dc. For

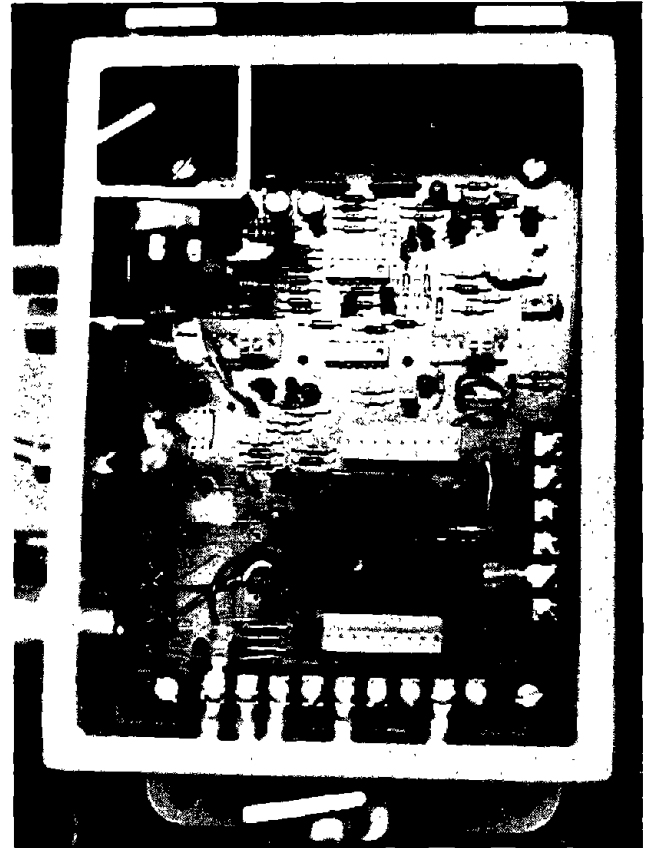


FIGURE 4. - Infrared electronic control card.

testing purposes, the electronics control circuit card was ordered unmounted. It was then adapted for 24-V dc operation, and mounted in a National Electrical Manufacturers Association (NEMA) 12, type D enclosure, with appropriate holes added for power and sensor leads (fig. 4).

The system was field tested in three different locations over a period of several months. The first test was on a Terex 90C FEL. At the time, the 90C was a preproduction, pilot model machine, using an 8- to 11-yd<sup>3</sup> bucket on a field trial and demonstration. The sensors were mounted on adjustable brackets welded to the frame on either side of the radiator grille, about 6 ft above ground level. (See figures 5 and 6.) The control box and annunciator were mounted in the cab on a dash panel located to the right of the operator. Connecting cables between the two, and a cable connecting the backup alarm to the control box, were run under the loader deck alongside

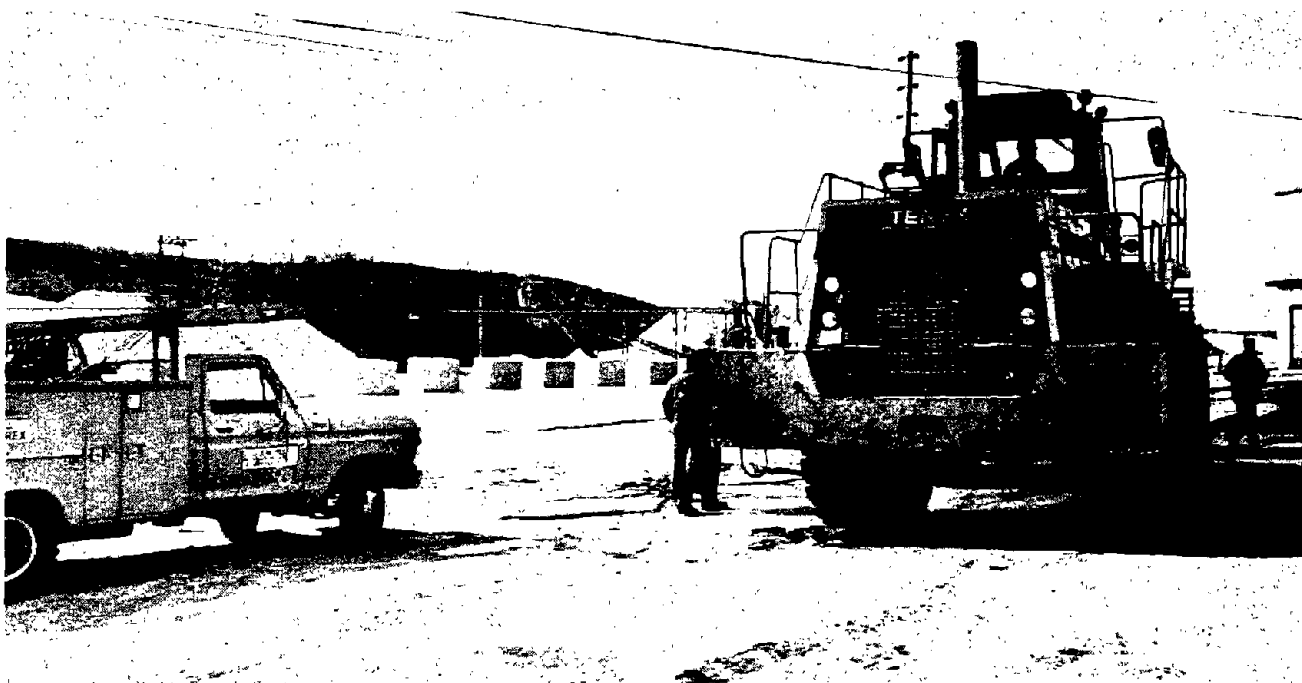


FIGURE 5. - Infrared sensor on a Terex 90C.



FIGURE 6. - Close-up of infrared system sensor on a Terex 90C.





FIGURE 7. - Infrared sensor system on a Clark 275.



FIGURE 8. - Infrared system on a Caterpillar 980.

existing cable and hose runs. The connecting cables for the sensors, which consisted of two-pair shielded conductors (Belden 8723), were supplied by the manufacturer. For convenience of installation, connectors were inserted in the sensor cables approximately 5 ft from the sensor. Power was obtained from a terminal on the oil pressure switch, which meant the system would be on if the vehicle's engine were running. The FEL's backup alarm was connected to the system to sound if the sensors detected an object in their coverage area, regardless of the direction of the FEL travel.

The IR system was on the FEL for approximately 6 months during the early spring and summer of 1984. Throughout the testing, the IR system revealed many weaknesses. Reports from the mine indicate that after 2 weeks of use, the system became sensitive to the vehicle's engine speed. Above 1,200 rpm it worked properly, but below this speed it had no sensitivity and false-alarmed. Dust accumulation on sensor windows caused the sensors to register a loss of sensitivity, but this condition was easily corrected by cleaning the windows. Despite these flaws, the principal operator of the FEL liked the system because it was useful in stockpiling operations and maneuvering near the highwall. The operator also felt the system had prevented a couple of collisions.

At the conclusion of the testing period, an examination of the system revealed that the sensor leads between the control electronics and the sensors were worn and abraded in several places, causing short circuiting of the leads. This accounted for the poor operation of the system and indicated the need for better routing and securing of the leads.

The Bureau has mounted similar STI systems on smaller FEL's: a Clark 275 (fig. 7) and a Caterpillar 980 (fig. 8). The installations were much the same as previously described except for the physical placements of the sensors and control electronics, which were located according to the situation and available cab space. Flexible, watertight conduit was used in

the Caterpillar 980 installation to protect the leads where they ran between the cab and the sensor location. These systems were affected by dust, sunlight, and reflected light from white sand, making their overall performance marginal.

### Search-Eye

Another IR based system, known as Search-Eye, manufactured by Global Fabrications Co., Ltd., in Weston, Ontario, Canada, was also tested. This system was designed primarily for use on street and alley refuse haulage trucks. It operates on the same principle as the previously described STI system. Reflected IR light from the detected object is sensed and activates a warning buzzer and light. It is different from the STI system in its packaging and control electronics. The Search-Eye system uses three sensor-detectors spaced across the width of the vehicle. An IR beam is spread horizontally, and vertically (though to a lesser capacity), by two long, narrow, plastic lenses. This results in a wide field of coverage for each sensor [about 1 m (39 in)], but severely shortens the range of detection to 1.1 m (3.7 ft). This system was checked in the laboratory and briefly in the field on a FEL, but its detection range was too short for use in large mine vehicles.

### ULTRASONIC SENSING SYSTEM

Global Fabrications Co. also manufactures an ultrasonic-based object sensing system, under the trade name Sonic Radar. The principle on which the system operates involves the emission of an ultrasonic sound burst, followed by detection of a reflected energy wave returned to the source by contact with an object. The system is composed of four major parts: two front sensors, two rear sensors, control box, and alarm; however, the front sensors were not used in field testing because they do not affect the rear blind area for mining applications (fig. 9).

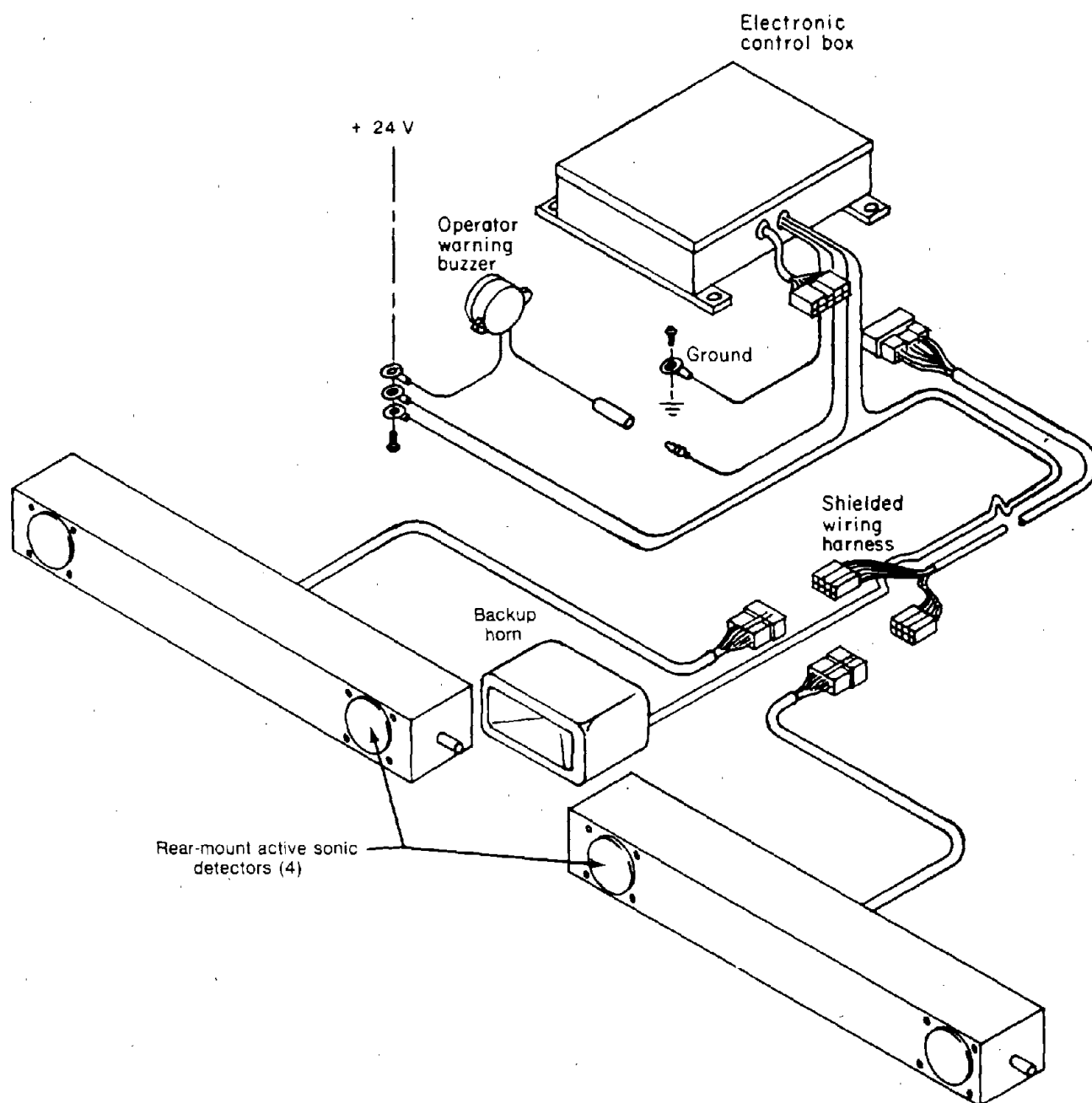


FIGURE 9. - Schematic diagram of an ultrasonic detection system.

The Sonic Radar system is installed in much the same way as the IR systems, although the sensors require more room. Also, the sensors must not be mounted where the engine radiator cooling airstream can flow around them, as this airflow can cause the system to false-alarm. Figures 10 and 11 show one

typical location for sensors on a FEL. The system operates from a 12- or 24-V dc electrical system. The sensors are in a 14-gauge steel housing, with end brackets provided for swiveling the housing to aim the beam. Two systems were field tested, on a Caterpillar 988B loader and a Clark 275C loader. (See table 1.)



FIGURE 10. - Ultrasonic detection system installed on a Clark 275C.

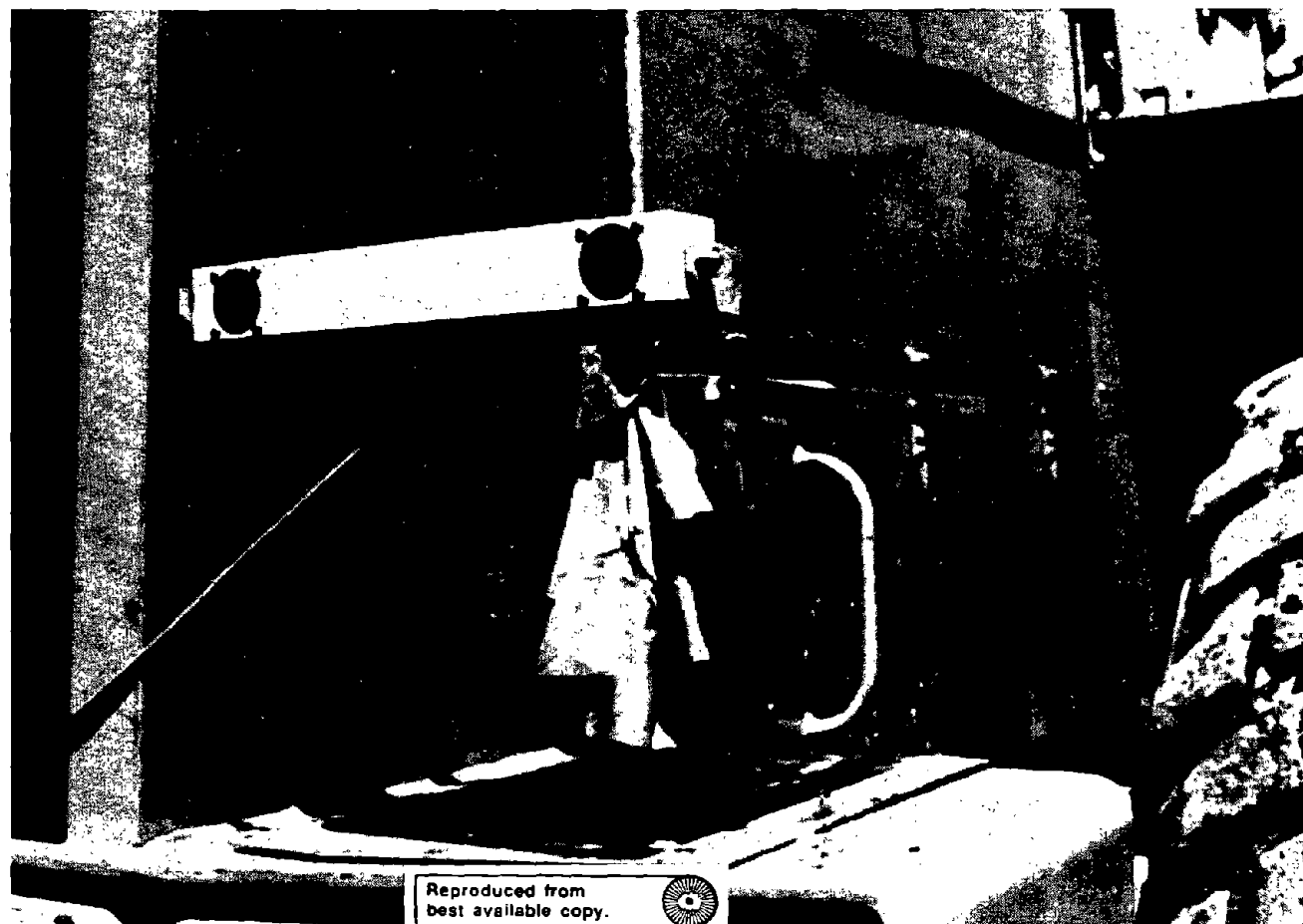


FIGURE 11. - Close-up of ultrasonic sensors.

The system was connected to energize the rear sensors when the vehicle's engine was switched on. The sensors will detect any object up to 4.4 m (16 ft) away from the sensor. When an object is detected, a pulsating alarm sounds in the cab. When the object is within an adjustable range of 0.9 to 2.7 m (3 to 9 ft), the alarm will change to a constant tone.

Though not specified as an option, an external solid-state alarm was connected to the control box, so that it would sound upon detection of an object. Both the external alarm and the in-cab alarm will sound when an object is sensed within the system's detection zone. Figure 12 depicts how the zone was measured, with the black cord on the ground outlining the zone. The sonic wave coverage is actually somewhat conical near the FEL because of the separation between the right and left sensors. The coverage overlaps at 9 ft from the FEL when the transducer pairs are placed 4-1/2 ft apart; this produces a zone of nondetection near the FEL in the area that the spreading cones do not reach.

The system detects objects about 1 ft above ground level when the full cone is developed 9 ft from the FEL. Beyond 9 ft, the outline of coverage was well defined and rectangular in shape; overall the coverage area measured approximately 11 by 17 ft.

One of the two Sonic Radar systems currently being tested is on a Clark 275, and the other is on a Caterpillar 988B. At last report, both systems were working well and physically withstanding the dusty and harsh mine environment. The mine managers like the systems because of the reduction of noise from the back-up alarm, as well as the positive safety warning given upon detection of an object in the rear blind area.

#### DOPPLER RADAR SYSTEM

A short-range Doppler radar system, manufactured by Con-Serv, Inc., Omaha, NE, was recently made available for testing. Called an "Electronic Mirror," it is a radar device that uses the Doppler shift principle to detect the presence of a moving target within its range. The

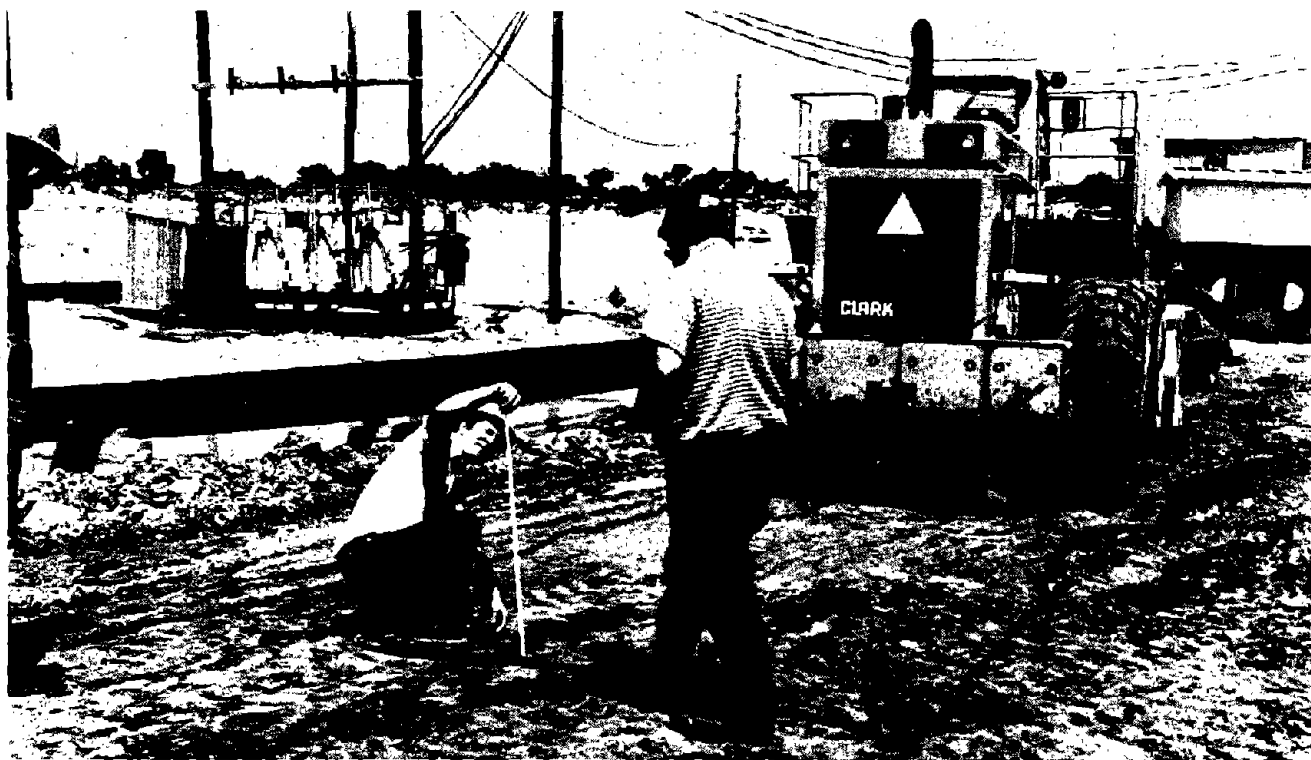


FIGURE 12. - Measuring the detection zone.

system is made up of a transceiver, an antenna, an intermediate frequency amplifier, and an audiovisual alarm.<sup>6</sup> The transceiver consists of a Gunn diode

<sup>6</sup>Con-Serv, Inc., has also manufactured similar Doppler radar devices for use on school buses. Such a device is credited with saving the life of a child in Valdez, AK, in February 1986, when the buzzer alerted the bus driver to the presence of the child "retrieving a football that had rolled under the bus." The school district had contacted Russell Griffin of the Bureau regarding acquisition of this safety equipment. This lifesaving incident occurred just 1 day after the sensor was installed on the bus.

mounted in a waveguide cavity, providing a transmitter, local oscillator, and a barrier mixer for the receiver. Output frequency is factory preset at 10.525 GHz and the power output is 5 mW. The rest of the circuitry is card-mounted and treated with conformal coating to prevent moisture and salt corrosion.

These units are mounted in an environmentally sealed, high-impact, plastic housing (fig. 13). A splashproof, four-conductor connector is mounted on the rear of the unit to provide for power and connections to the audiovisual alarm and the vehicle's backup alarm. Two different types of antennas are available for use on various sized vehicles. They are constructed of diecast and machined alu-



FIGURE 13. - Close-up of a Doppler radar detection system.

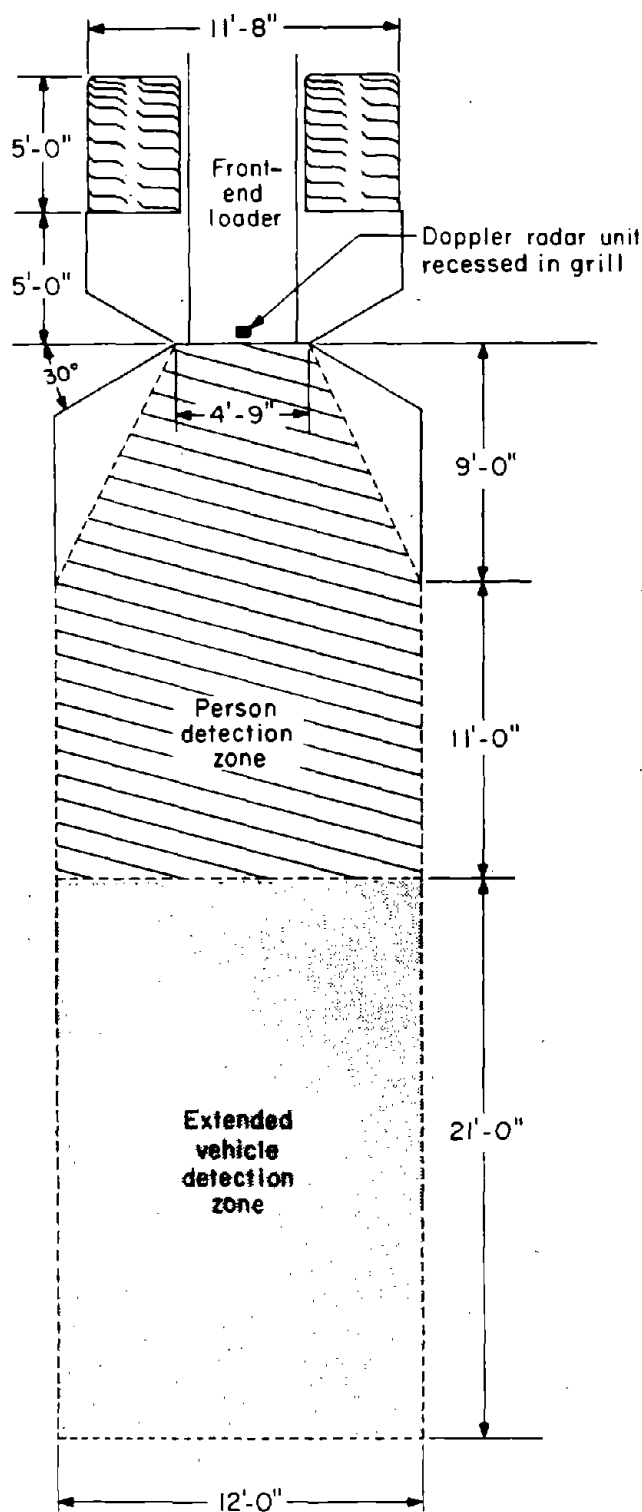


FIGURE 14. - Detection zone of a Doppler radar system.

aluminum and flange mounted directly to the transceiver waveguide cavity, eliminating the effects of noise and false responses. Antenna range is adjustable to accommodate the needs of different-sized vehicles for blind area coverage. An integrally molded projection on the housing provides a means of mounting the unit on a universal bracket, which is then mounted on the rear of the vehicle.

A Clark 275C FEL, a Caterpillar 992 FEL, and a Caterpillar 988 FEL were used during several months of testing the unit for durability and functionality. Figure 14 diagrams the area coverage in which an object can be sensed. This area will vary depending on the height, angle of declination, and sensitivity adjustment of the radar unit.

A similar unit was also tested at the Bureau's Twin Cities facility by a contractor using a Caterpillar 910 FEL. After installation, the operator backed up towards an anthropomorphic dummy posed in a seated position, placed on the ground (fig. 15). The operator received a warning at the 12- to 18-ft range (depending on the angle of approach), and was able to stop in time on each trial. The range of the unit is adjustable and will easily accommodate any FEL. One specially designed system was capable of detecting a person at 28 ft but was not field tested.

The units have stood up well in the mine environment and operated satisfactorily. In one case, the mine ordered a unit on its own to equip a second FEL. The feeling seems to be universal that such devices will not only protect the vehicle from rear collisions, but also, when connected to the backup alarm required on the vehicle, enhance safety aspects by reducing the amount of unnecessary noise.

#### POSSIBLE HARDWARE IMPROVEMENTS

Each of the tested systems has limitations of width or distance coverage. In the case of the IR systems, there is a tradeoff between projection distance and width of beam with a given intensity. This is also true with the ultrasonic



FIGURE 15. - Testing a Doppler radar system with an anthropomorphic dummy.

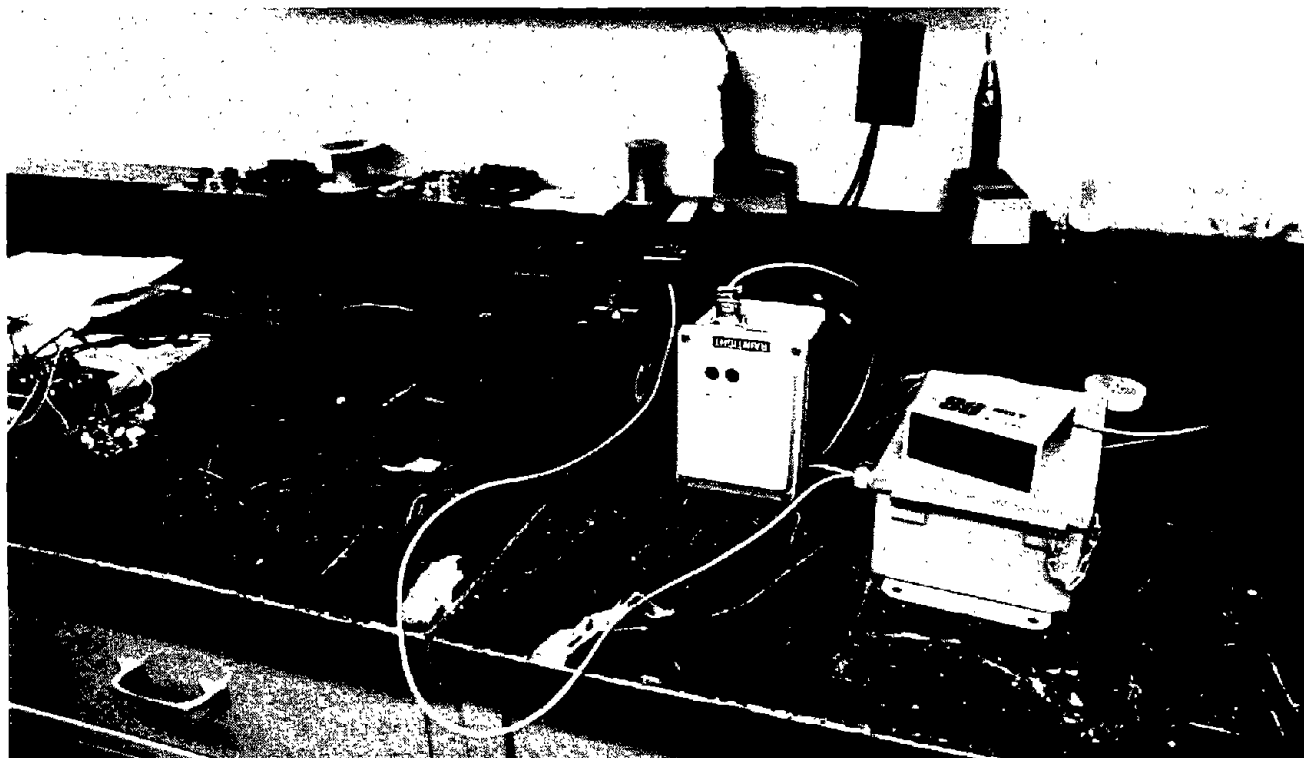


FIGURE 16. - Prototype synthesized voice warning system.



system, but sonic waves naturally disperse more and are difficult to project. As efficiencies in light-emitting diodes and sonic transducers are improved, along with the development of different driving and receiving circuit techniques, both range and width of coverage should increase.

One easily implemented improvement in any alarm system would be the substitution of voice warning output for audio alarm output. Voice synthesis and digitizing has made great strides and

continues to come down in cost. There is also evidence that voice warning is more effective in attracting attention. Such a prototype system was fabricated in the laboratory to demonstrate the applicability of the improvement. (See figure 16.)

Another improvement would be to include a test switch that could power systems for preshift vehicle inspection and daily testing of the alarm. This would allow checking the system without starting the FEL and placing it in reverse gear.

### INSTALLATION TIPS

During the course of the installation and field trials, several techniques and procedures were found to be of help in maintaining the operating systems. The following tips are listed to aid in the field installation of these systems.

1. Protect long runs of wire and cable from abrasion by installing them in conduit. If possible, it is best to follow existing runs of hoses, wires, or cables. The liquidtite type of conduit is easy to use. Once the conduit is in place, it can be fastened with wire ties and the necessary wires and cables pulled through it with the aid of a "snake." Each end of the conduit should be finished off by using a bushing. Also, run wire, cable, or conduit, to allow for maintenance and removal of engine components with as little disturbance as possible.

2. Use some type of environmentally protected housing for the electronics. A NEMA 4- or 12-type box is probably the

easiest to obtain. If possible, locate the control box inside the cab.

3. Physically isolate components from vibration effects if the manufacturer has not done so.

4. Locate and mount the sensors in such a way as to allow for easy removal for engine maintenance access. Also, make sure they cannot easily be knocked off or broken during machine operation.

5. Keep ultrasonic type sensors away from the engine cooling airstream. Mount the IR types where the least amount of dust can accumulate on them. In both cases, allow the sensor a clear view to the rear area.

6. Use an appropriately sized fuse in the power connection to the system.

7. Consult an individual familiar with the electrical wiring layout of the vehicle to help determine the best place to connect for primary power.

### DISCUSSION

#### INFRARED SYSTEMS

IR object detection systems do not perform well in mines. False alarms can be triggered by bright sunlight and reflections of the mine ground (such as white sand). Their range depends upon the reflectivity of the detected object, which is variable due to factors like soft clothing, hard hats, reflective tape, steel machinery, and reflectors on machinery. Because of the narrow beam

pattern, arrays of sensors must be employed and reflectivity within the mine must be made more uniform. Increasing the number of sensors increases the cost and system complexity yet decreases the system's reliability. The narrow beam from a sensor, mounted above the rear bumper for protection, does not have the vertical coverage to detect a person sitting or kneeling on the ground. Detection of this type of object would require more sensors angled downwards

toward the ground. The addition of reflectors to clothing and equipment is necessary to insure uniform reflectivity in a mine. This would promote a uniform detection range, but it would be expensive to initiate and maintain. For these reasons, IR technology is the least attractive method of detecting objects in the rear blind area.

#### ULTRASONIC SENSING SYSTEMS

Ultrasonic object detection systems utilize transverse mechanical waves at the low end of the ultrasonic spectrum. The Polaroid transducer operates with 50, 53, 57, and 60 kHz pulses and has a beam angle of 15° from the electrostatic combination transmitter-receiver. The Sonic Radar unit uses a separate piezoelectric transmitter and receiver operating at 32.8 kHz, with a beam angle measuring approximately 34°. This system provided a nearly rectangular detection zone, but its range of only 17 ft is too short for large machines.

Another problem with ultrasonic systems is that the wave velocity is considerably slower than IR light or microwaves (used with Doppler radar systems). Several waves must be sent, received, and compared in order to insure that the sample of wave travel time is accurate. At a velocity of 1,090 ft/s in air, a wave requires 1/1090 s times 2 ft, or 1.83 ms, for each foot of detection range (travel distance to and from target). If many waves are sampled (Polaroid uses fifty-six 1-ms pulses), the time between initial detection and operator warning or system reaction time may become great

enough to preclude warning the operator in time to stop the vehicle.

In field tests, the Sonic Radar's system reaction time was approximately 0.5 s for an object at the edge of the detection zone. This long system reaction time, coupled with a short detection range, limits the use of this type of system to smaller FEL's operating at lower speeds.

#### DOPPLER RADAR SYSTEMS

Doppler radar systems use the Doppler frequency shift principle to detect objects. This requires relative motion between the system and the object being detected. The beam pattern is controlled by the design of the antenna. The detection range is controlled by the power output, sensitivity, and shape of the antenna, as well as by the "radar profile," or ability to reflect microwaves, of the object to be detected. Virtually any detection zone range and shape can be produced; however, the radar profile of objects in mines is variable. In general, larger, more reflective objects can be detected at longer ranges. In-mine tests demonstrated that a system capable of detecting a person at a distance of 20 ft would detect a small car at 40 ft and a large metal building at several hundred feet. In most operations, detection of large objects is not a problem, as FEL's usually back away from stockpiles and mine structures such as hoppers.

The Doppler radar systems are not affected by lightning, rain, fog, snow, or wind, as were the other types of systems.

#### CONCLUSION

The Bureau of Mines experimented with IR light, ultrasonic wave, and Doppler radar technology to develop a system capable of detecting an object in the rear blind area of mobile mining equipment. This system sounds an alarm only when a collision hazard exists, reduces

the semicontinuous noise of backup alarms, and eliminates the false alarm aspect of current backup alarms. Of the three technologies, Doppler radar proved to be the best compromise because of its immunity to various weather conditions.

## APPENDIX.--SOURCES OF EQUIPMENT

Scientific Technology, Inc.  
1201 San Antonio Road  
Mountain View, California 94043

Global Fabrications, Ltd  
4 Twyford Road  
Toronto  
Ontario, Canada M9A1V7

Con-Serv, Inc.  
3801 Dahlman Avenue  
Omaha, Nebraska 68107

Polaroid Corporation  
Ultrasonic Components Group  
119 Windsor Street  
Cambridge, Massachusetts 02139

